



ERMES: NUMERICAL TOOL FOR SAR COMPUTATIONS

SAR TOOL VALIDATION REPORT

Project SMART - WP6 Task 6.5 Deliverable 6.5.3

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1. SCOPE

This document contains the description and validation of the SAR tool named ERMES which had been developed by CIMNE in the SMART project.

2. REFERENCES

- [1] Rubén Otín, "*A High-Order Nodal Finite Element Formulation for Microwave Engineering*", 24th International Review of Progress in Applied Computational Electromagnetics (ACES 2008), March 30 - April 4, 2008, Canada (<http://aces.ee.olemiss.edu/>).
- [2] Rubén Otín, "*Regularized Maxwell equations with nodal elements as an alternative approach to the edge-based FEM formulations*", 9th International Workshop on Finite Elements for Microwave Engineering (<http://www.lte.uni-saarland.de/fem2008/>).
- [3] Rubén Otín, "*Regularized Maxwell equations and nodal finite elements for electromagnetic field computations*", Electromagnetics, ISSN: 0272-6343 (<http://www.tandf.co.uk/journals/titles/02726343.asp>) (Provisional publication date in mid 2009).
- [4] Rubén Otín, Javier Mora, "*El Método de los Elementos Finitos Aplicado a las Ecuaciones de Maxwell Regularizadas en Presencia de Singularidades*", V Encuentro Ibérico de Electromagnetismo Computacional, 25-27 Abril 2007, Aiguablava (Spain) (<http://www.tsc.upc.edu/eiec2007/default.php>).
- [5] EADS SN et al, *SMART T0+30 report - deliverable 1.7*, February 2008
- [6] SRF Moyano, *SMART WP5 Task 5.3 report - deliverable 5.3.2*, December 2007.

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3. TERMINOLOGY

3.1 ABBREVIATIONS

ERMES	Electric Regularized Maxwell Equations with Singularities
FEKO	Field Computation for Objects of Arbitrary Shape (In German)
FEM	Finite Element Method
GPS	Global Position System
GTD	Geometrical Theory of Diffraction
HORUS	High ORder elements Un-gauged near the Singularity
MoM	Method of Moments
Mod(E)	Electric field modulus
PMR	Personal (or Professional) Mobile Radio
PO	Physical Optics
SAR	Specific Absorption Rate
UTD	Unified Theory of Diffraction

3.2 DEFINITIONS

ERMES	SAR tool developed by CIMNE in the SMART project.
FEKO	Commercial software product for the simulation of electromagnetic fields (www.feko.info).
GiD	A universal, adaptive and user-friendly graphical user interface for geometrical modelling, data input and visualisation of results for all types of numerical simulation programs (www.gidhome.com).
HORUS	Finite element formulation behind ERMES.

4. SAR TOOL OVERVIEW

The **Specific Absorption Rate** (SAR) is a measure of the rate at which energy is absorbed by a body when exposed to electromagnetic fields. SAR measures are necessary if we want to design safe PMR devices. To save time and money doing these measurements, numerical simulations play a key role.

Numerical solutions based on integral techniques are quite accurate but they are not well adapted to this situation. The major problems are associated with computer times and memory requirements. By the other way, a volumetric method like the finite element method (FEM) works efficiently with inhomogeneous materials and complex geometries.

The aim of CIMNE in WP4 is to implement a FEM based code able to solve efficiently SAR problems. The numerical algorithm we propose is based on the weighted regularized Maxwell equations with high-order nodal elements.

The proposed formulation will give well-conditioned sparse matrices, easy to solve with iterative solvers. More established FEM formulations, based on edge elements, are more hardware demanding and give ill-conditioned matrices which are difficult to solve with iterative solvers. The need to use direct solvers in the edge element based formulations limit severely the size of the problem that a given computer can manage.

But, although this new approach brings some advantages, it also brings new problems: if the field is singular at some point of the domain, our method converges to a globally wrong solution. In figure 1 we can see the electric field near a step discontinuity. In figure 2 it is shown the solution obtained when the same problem is solved with the regularized Maxwell equations:

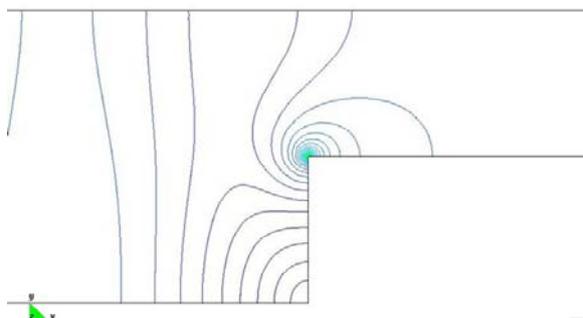


Fig.1 – Reference solution

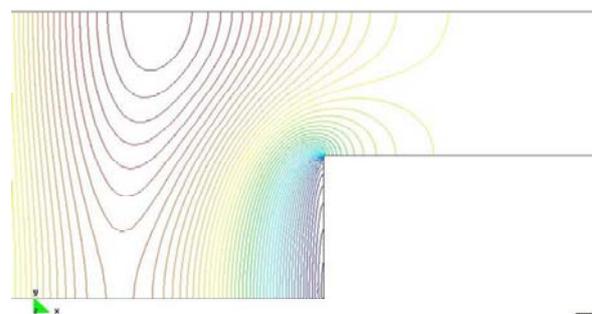
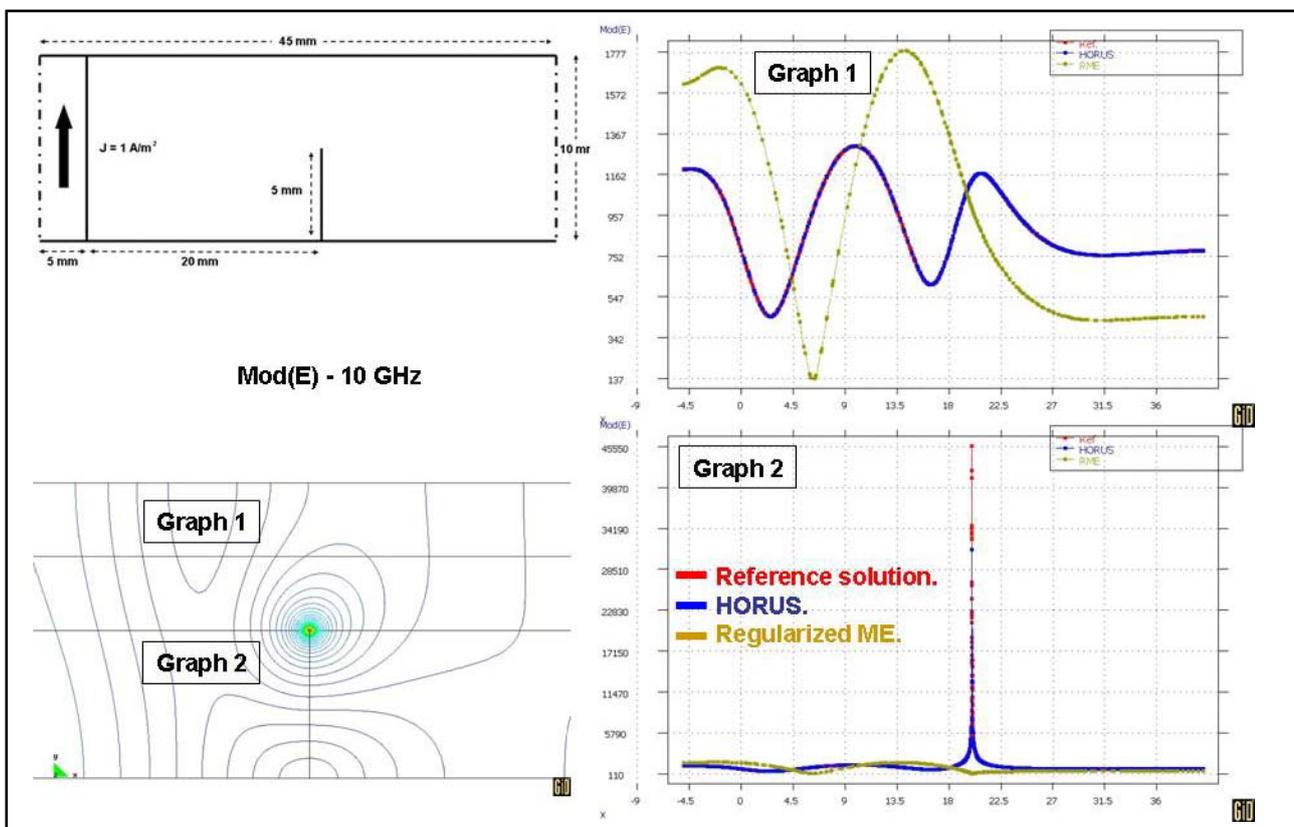
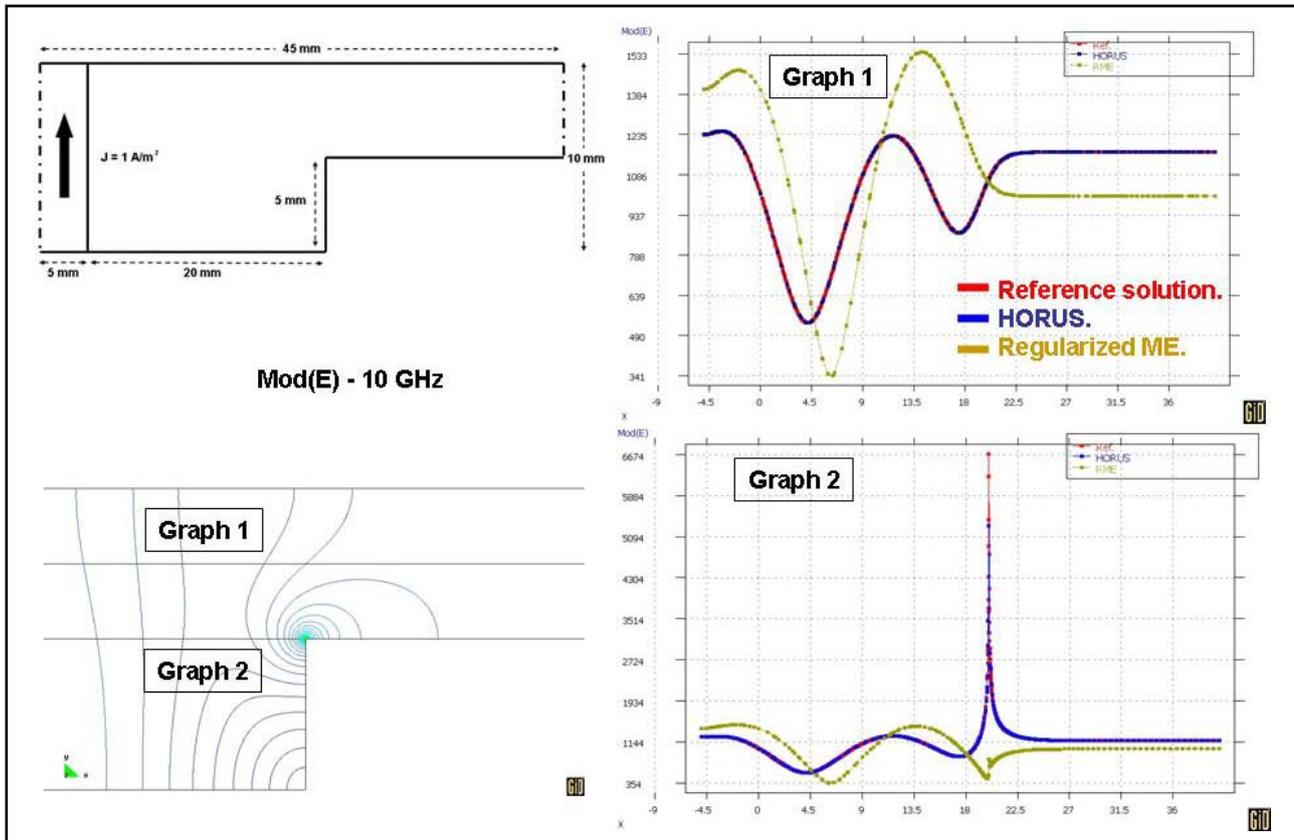


Fig.2 – Regularized Maxwell equations

The period from July 2006 to February 2007 was dedicated to overcome the new difficulty that appears when we try to solve numerically the regularized Maxwell equations. After testing different approaches in 2D, the simulations showed that the best option was to use high order Lagrangian elements un-gauged near the singularity, a method that was called **HORUS** (High Orders elements Un-gauged near the Singularity).

It can be seen in the next figures how the wrong solution given by the weighted regularized formulation is corrected after un-gauging the elements near the singularity:

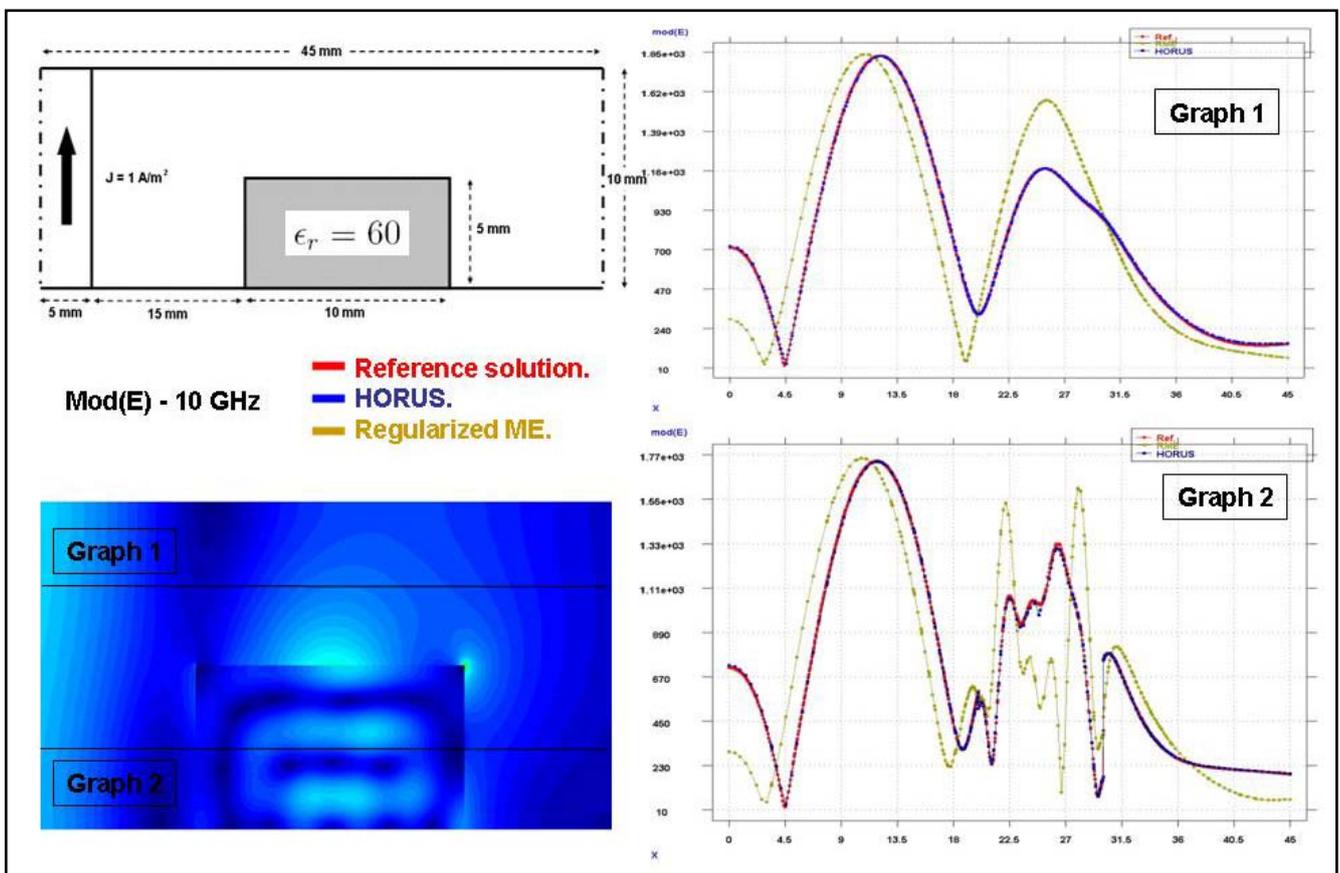
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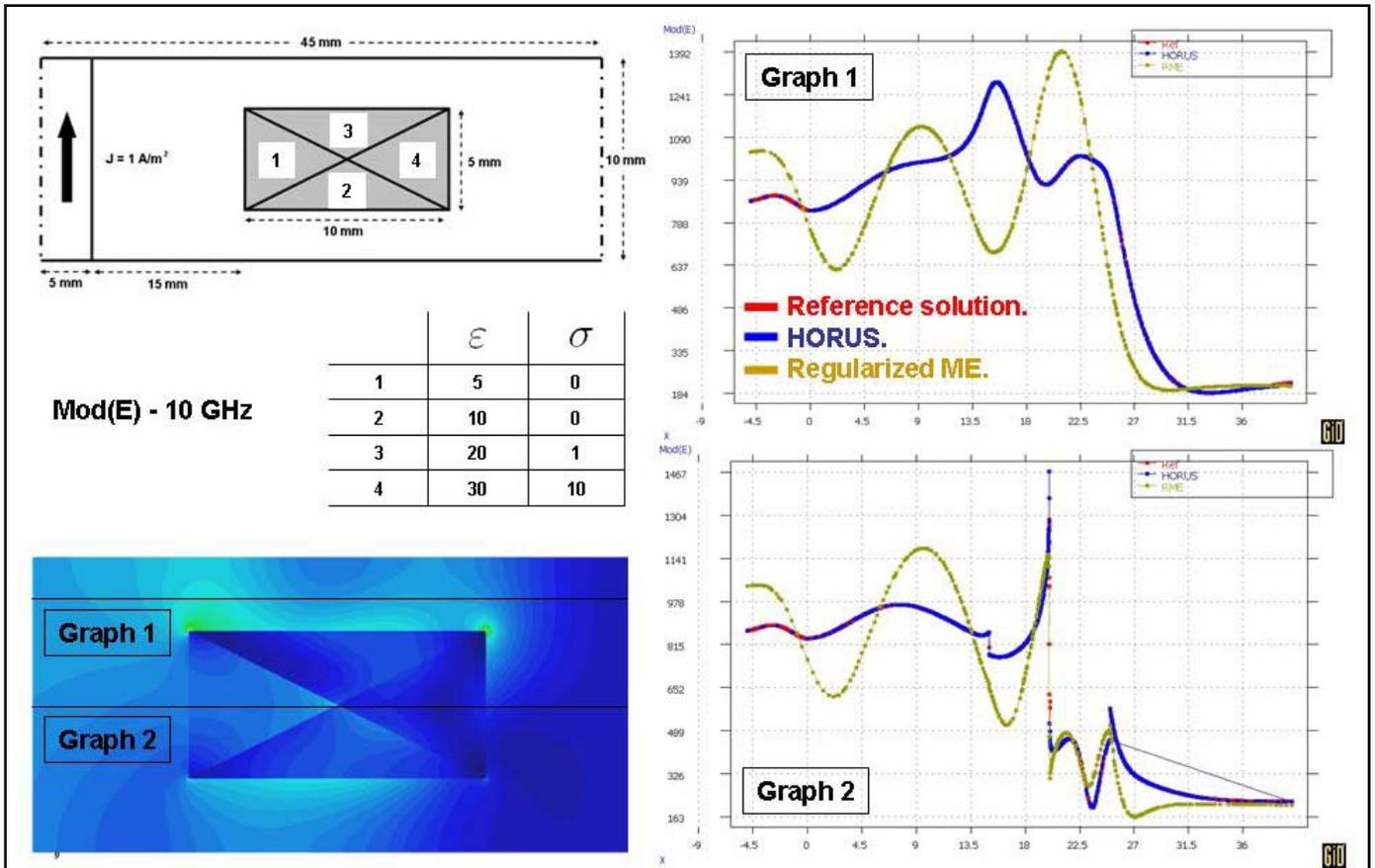


Figs. – Amendment of the solution after using HORUS.

Good solutions were obtained when using Lagrangian elements above the 3rd order. For these high-order elements only the one in contact with the singularity needs to be un-gauged. For 2nd order elements good solutions can also be obtained, but it is needed to un-gauge more layers around the singularity. In 3D problems, where efficiency is critical, the last approach will be selected, that is, we will solve with 2nd order elements and 3 layers of elements un-gauged around the singularities.

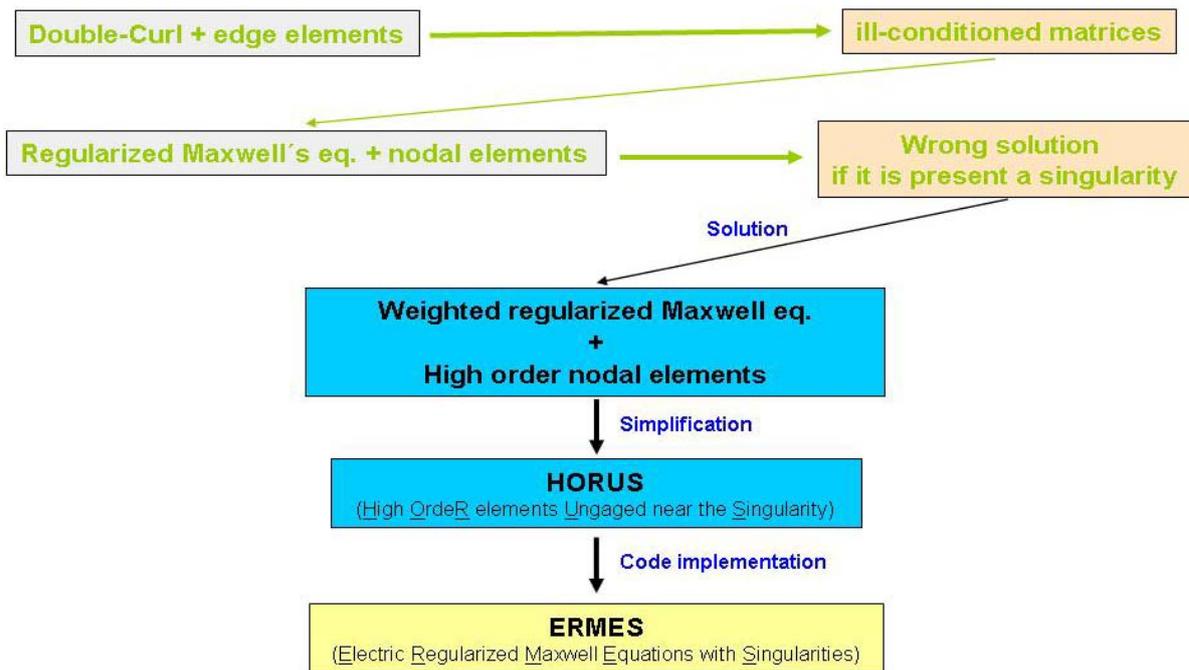
For the singularities that are present in corners, edges or intersection of dielectrics was applied the same procedure, given the same good results. The problem of defining a normal in the intersection of two or more dielectrics also was solved with success. In the interface between two different materials was used a double node formulation with a matrix product to relate the nodes in each side of the discontinuity surface. Results can be seen in the next figures:



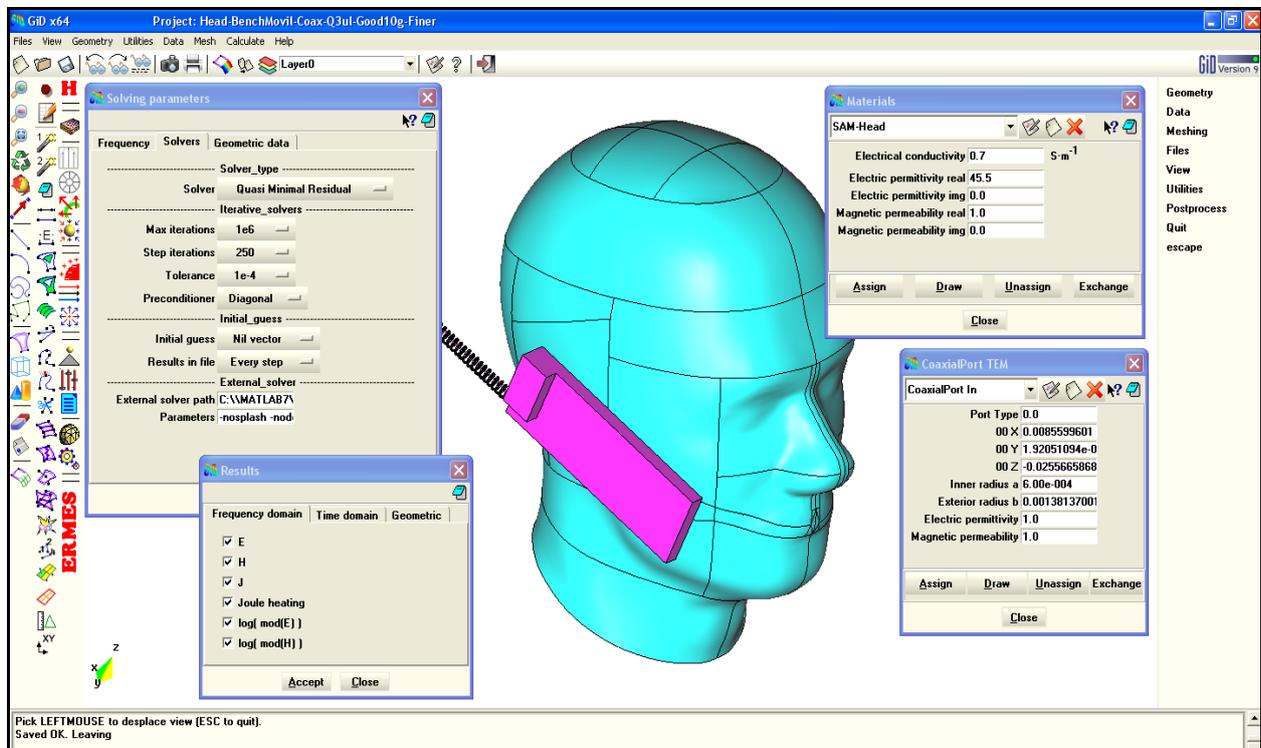


The method HORUS had been implemented and tested in 3D. To check the accuracy of HORUS was computed the scattering parameters of different microwave filters. The wide bibliography about microwave filters gives us a lot of benchmarking solutions to compare. The same code was also applied to solve SAR problems. In the next section will be shown some of the simulations performed.

The above mentioned code was called **ERMES** (Electric Regularized Maxwell Equations with Singularities). ERMES is the C++ implementation of HORUS and uses GiD (www.gidhome.com) as pre- and post-processor. In the next figure is shown the development roadmap of ERMES:



In the next figure is shown the graphical user-friendly interface of ERMES:



5. VALIDATION OF ERMES

The validation of ERMES for 3D problems was carried out in two stages:

First, the scattering parameters of some microwave filters were calculated with ERMES and compared with measurements and/or simulations performed with other methods. The measurements and the results of alternative methods were obtained from the broad bibliography available describing microwave devices.

Secondly, two benchmarks, more specifically related with the SAR problems we were interested in, were proposed by EADS SN. These SAR benchmarks were computed with ERMES and compared with measurements or with simulations performed by EADS SN using FEKO.

These two stages will be described in more detail along this section.

5.1 MICROWAVE FILTERS

During the period going from March 2007 to July 2007 the method HORUS was implemented and tested in 3D. HORUS is the finite element formulation behind ERMES, the C++ code that uses GiD as interface. To check the accuracy of HORUS was computed the scattering parameters of different microwave filters. The wide bibliography about microwave filters gives us a lot of benchmarking solutions to compare [1]. Next figures show some examples of the simulations performed:

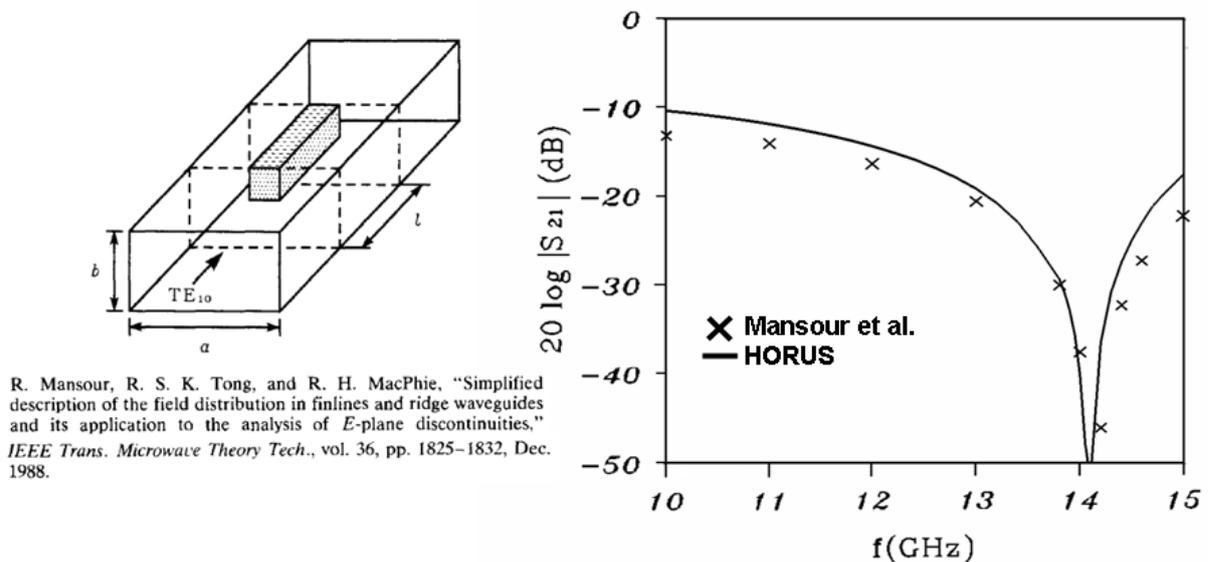


Fig. - Transmission coefficient of a ridge waveguide. Measurements versus simulation with ERMES using HORUS.

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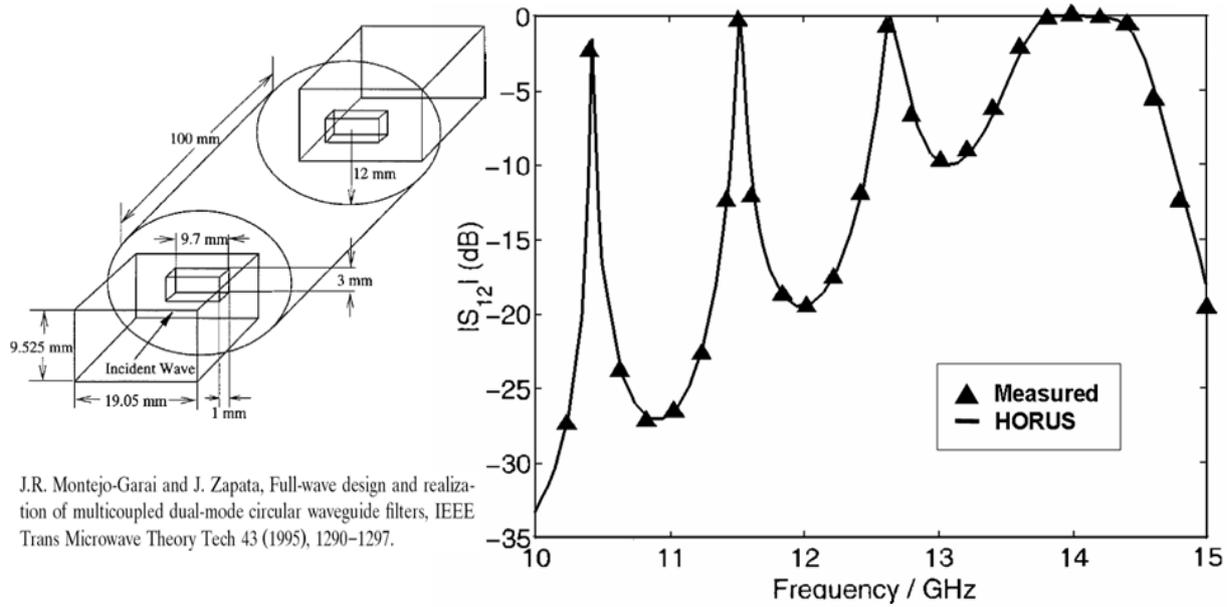


Fig. – Transmission coefficient of a circular waveguide filter. Measurement versus simulation with ERMES using HORUS.

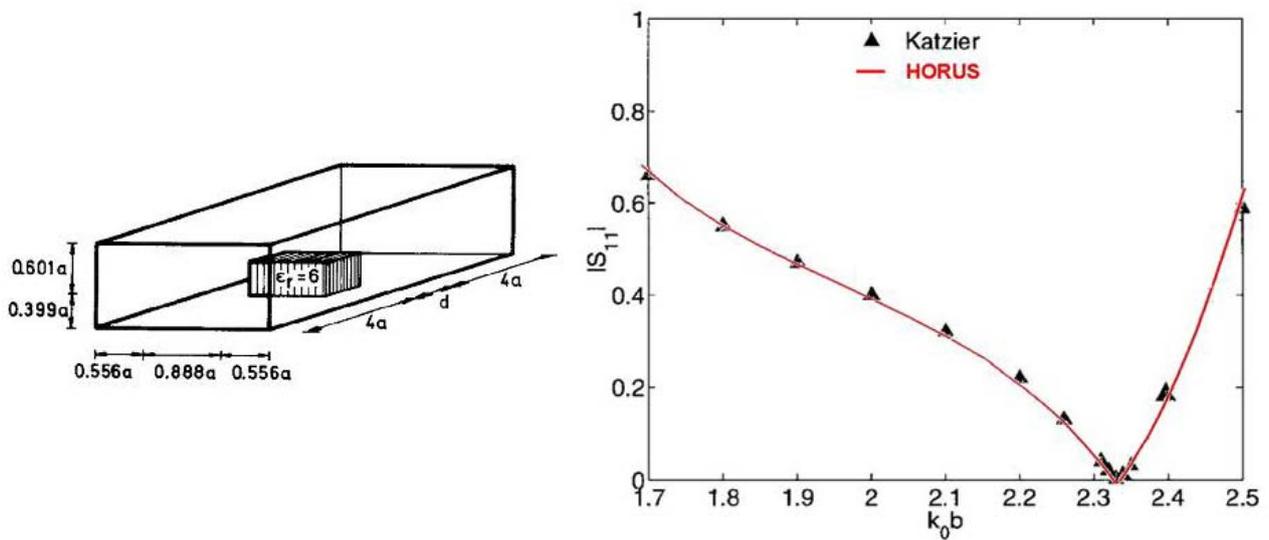


Fig. – Reflection coefficient of a waveguide with a dielectric obstacle. Katzier's method versus simulation with ERMES using HORUS.

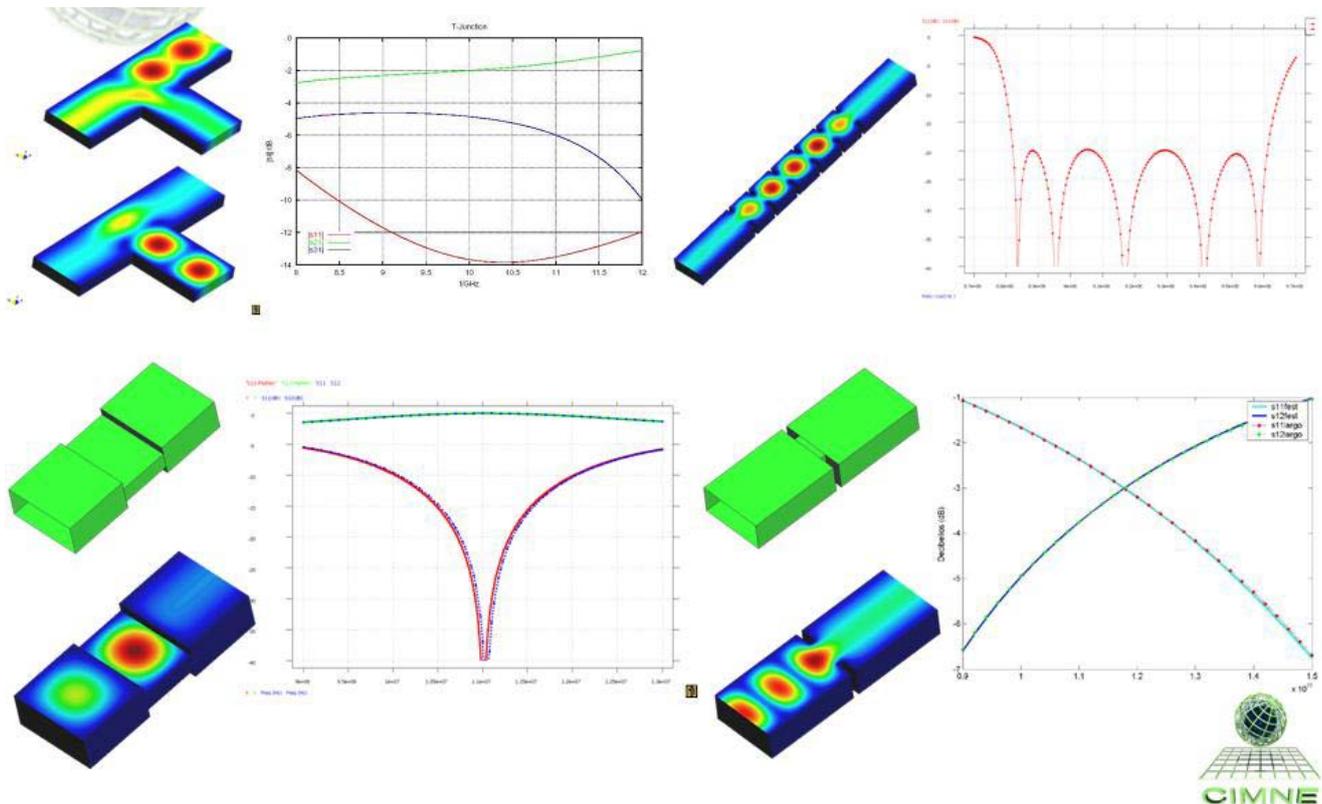


Fig. – Scattering parameters of some microwave filters. Semi-analytical method versus simulation with ERMES using HORUS.

5.2 SAR BENCHMARKS

Although ERMES had been successfully tested for simulate the scattering parameters of microwave filters, we need to know its performance when applied to SAR related problems. Different representative PMR applications and cases were simulated by EADS SN using FEKO MoM-FEM electromagnetic software. Final objective was the definition of example configurations for the validation of ERMES regarding the PMR needs and requirements. These examples of PMR configurations were simulated using the well-proven FEKO software and results were compared with existing measurements as much as possible.

Before the calculation of the SAR produced by the antennas designed in the SMART project two benchmarks were solved:

- 1) The PMR Mobile configuration (Police Motorbike case) in the UHF band (400 MHz band) and for 10W output power.
- 2) The PMR pedestrian configuration with the use of PMR Radio handhells in the UHF band (400 MHz sub-band) and for 2W output power.

The geometries and data needed for the simulations were supplied for EADS SN to CIMNE.

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1) Police motorbike configuration

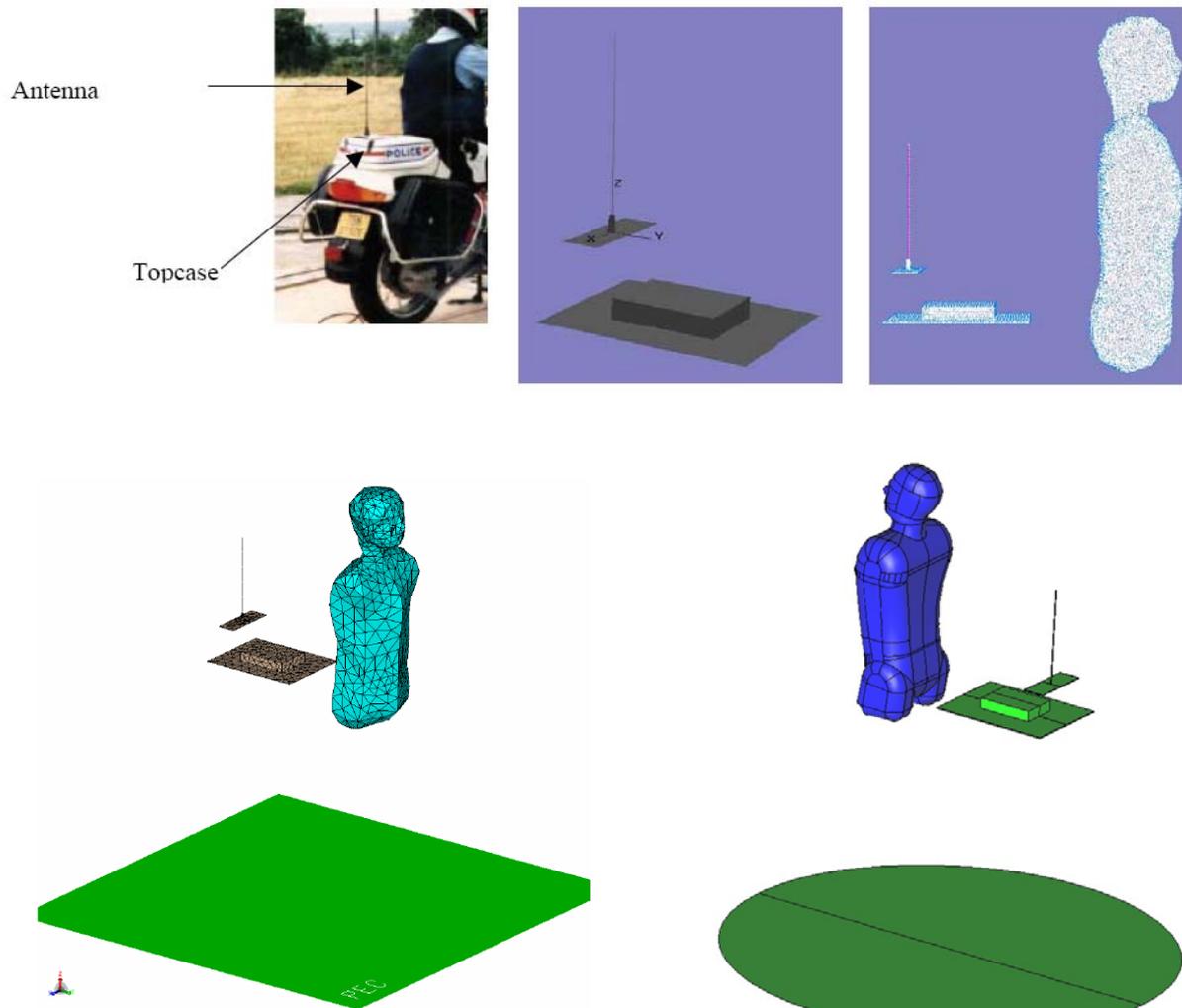


Fig - Real geometry and geometrical modelling with FEKO (left) and ERMES (right).

The input data for the simulations are:

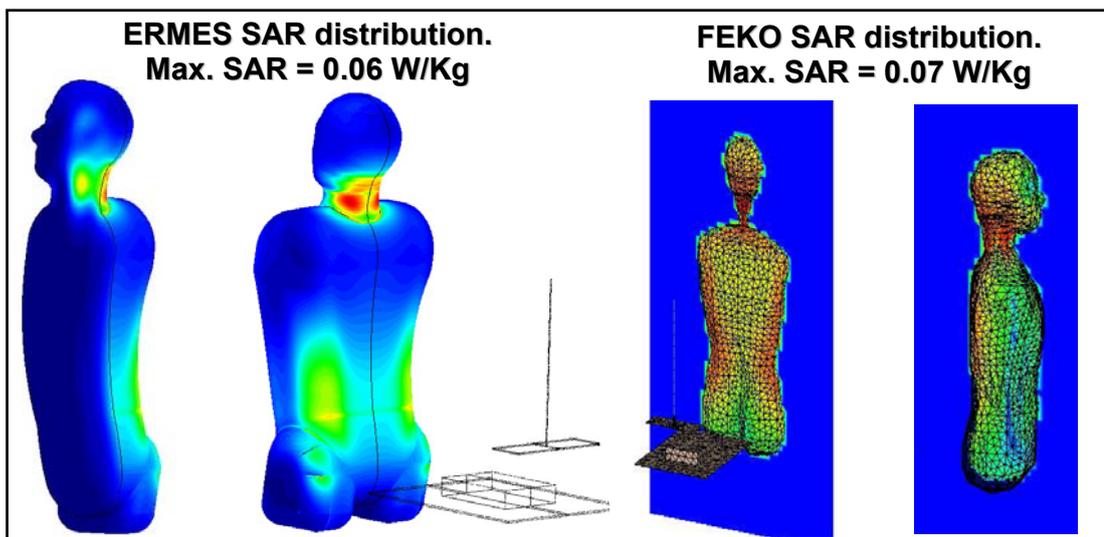
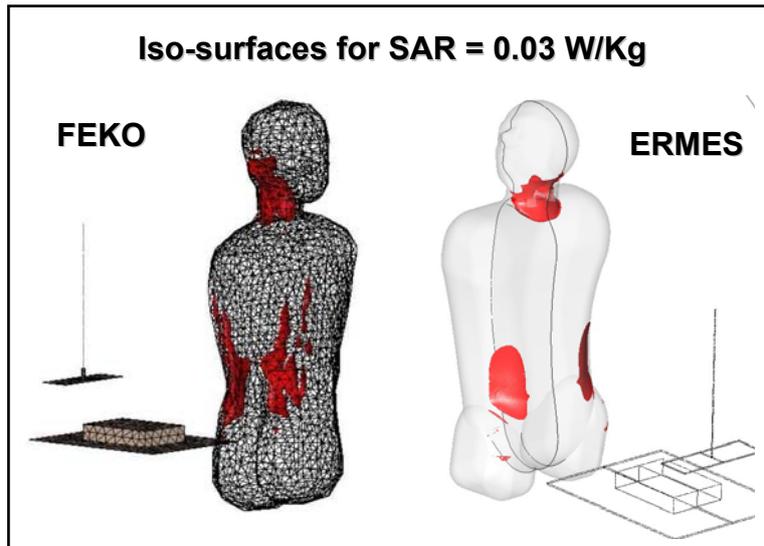
P = 10 W (40 dBm)
f = 406 MHz
 $\epsilon_r = 41.3$
 $\sigma = 0.58 \text{ S/m}$
 $\rho = 1000 \text{ Kg/m}^3$

and the distance from feeding point to:

-Body = 0.60 m
-Top case = 0.15 m
-PEC ground = 1.22 m

ERMES results are compared with the simulations performed by EADS SN using FEKO. The results are:

- **FEKO (EADS SN):**
SAR (average over 10g cube) = 0.06 W/Kg (back neck)
- **ERMES**
SAR (average over 10g cube) = 0.04 W/Kg (back neck)



2) PMR pedestrian configuration

The input data for the simulations are:

$$\begin{aligned}
 P &= 1.9 \text{ W (32.8 dBm)} \\
 f &= 390 \text{ MHz} \\
 \epsilon_r &= 45.5 \\
 \sigma &= 0.70 \text{ S/m} \\
 \rho &= 1000 \text{ Kg/m}^3
 \end{aligned}$$

and the distance from feeding point to **SAM head** = 0.02 m.

ERMES results are compared with measurements and the simulations performed by EADS SN using FEKO. The results are:

- **MEASUREMENTS:** SAR (average over 10g cube) = 4.16 W/Kg
- **FEKO (EADS SN):** SAR (average over 10g cube) = 3.20 W/Kg
- **ERMES:** SAR (average over 10g cube) = 4.39 W/Kg

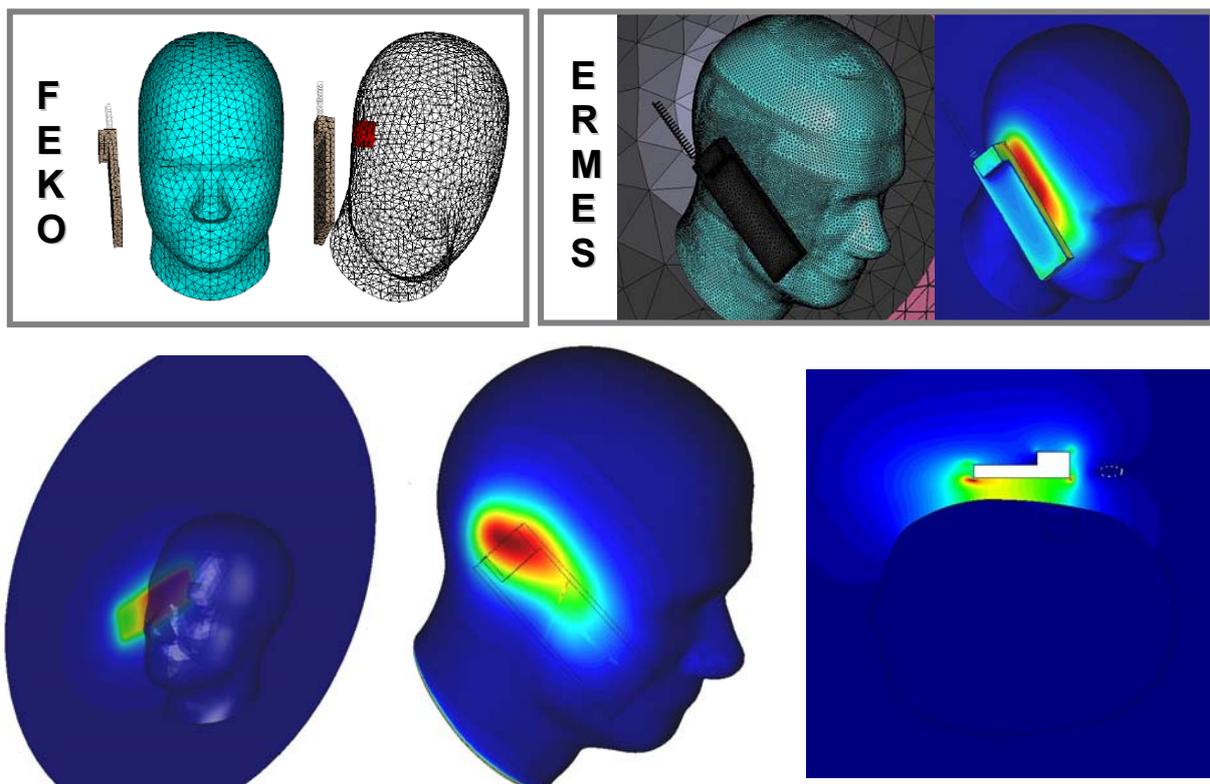


Fig - ERMES results from left to right: 1) mod(E) in a plane between PMR and head, 2) SAR distribution in the right side of the SAM head, 3) mod(E) in a transversal plane.

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6. APPLICATION OF ERMES TO SMART ANTENNAS

6.1 PMR-GPS ANTENNA (RADIALL)

The PMR-GPS antenna designed by Radiall is described in deliverable D1.7 [5].

The input data for the simulations are:

$$\begin{aligned}
 P &= 2 \text{ W (33 dBm)} \\
 f &= 400 \text{ MHz} \\
 \epsilon_r &= 45.5 \\
 \sigma &= 0.70 \text{ S/m} \\
 \rho &= 1000 \text{ Kg/m}^3 \\
 \epsilon_r (\text{substrate}) &= 3.0
 \end{aligned}$$

SAR values, averaged over 10g cube, for three different distances of the PMR-GPS antenna to the SAM head are:

Substrate surface - head 2cm:

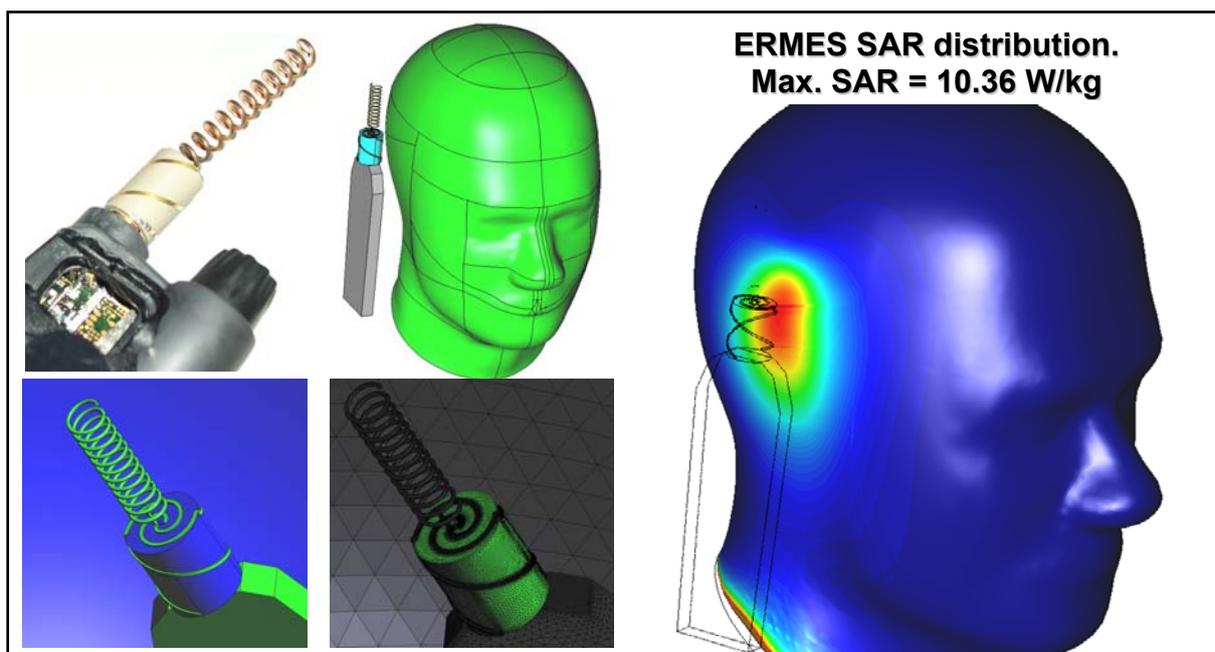
$$\text{SAR (average over 10g cube)} = 3.47 \text{ W/Kg}$$

Handset surface - head 2cm:

$$\text{SAR (average over 10g cube)} = 4.17 \text{ W/Kg}$$

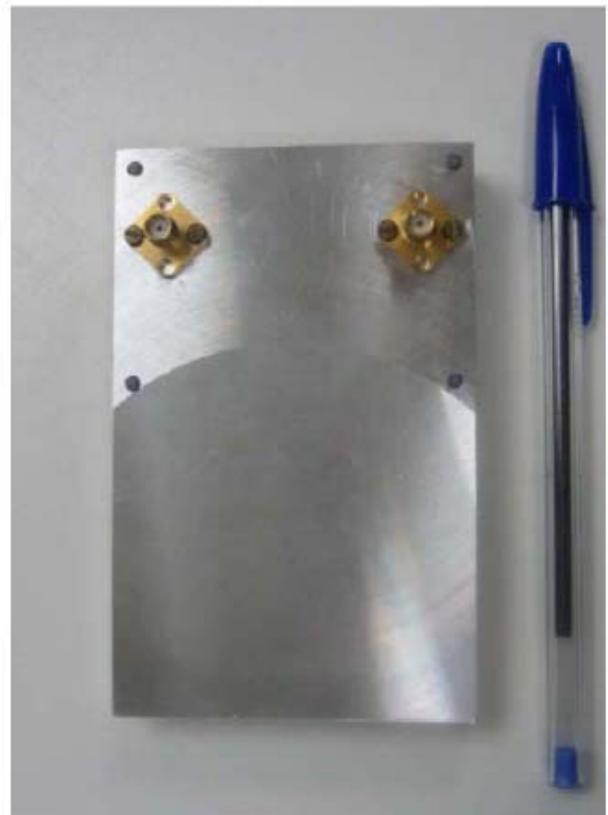
Feeding point - head 2cm:

$$\text{SAR (average over 10g cube)} = 4.56 \text{ W/Kg}$$



6.2 TRI-BAND MIMO ANTENNA (SRF MOYANO)

The Tri-band MIMO antenna designed by SRF Moyano is described in deliverable D5.3.2 [6].



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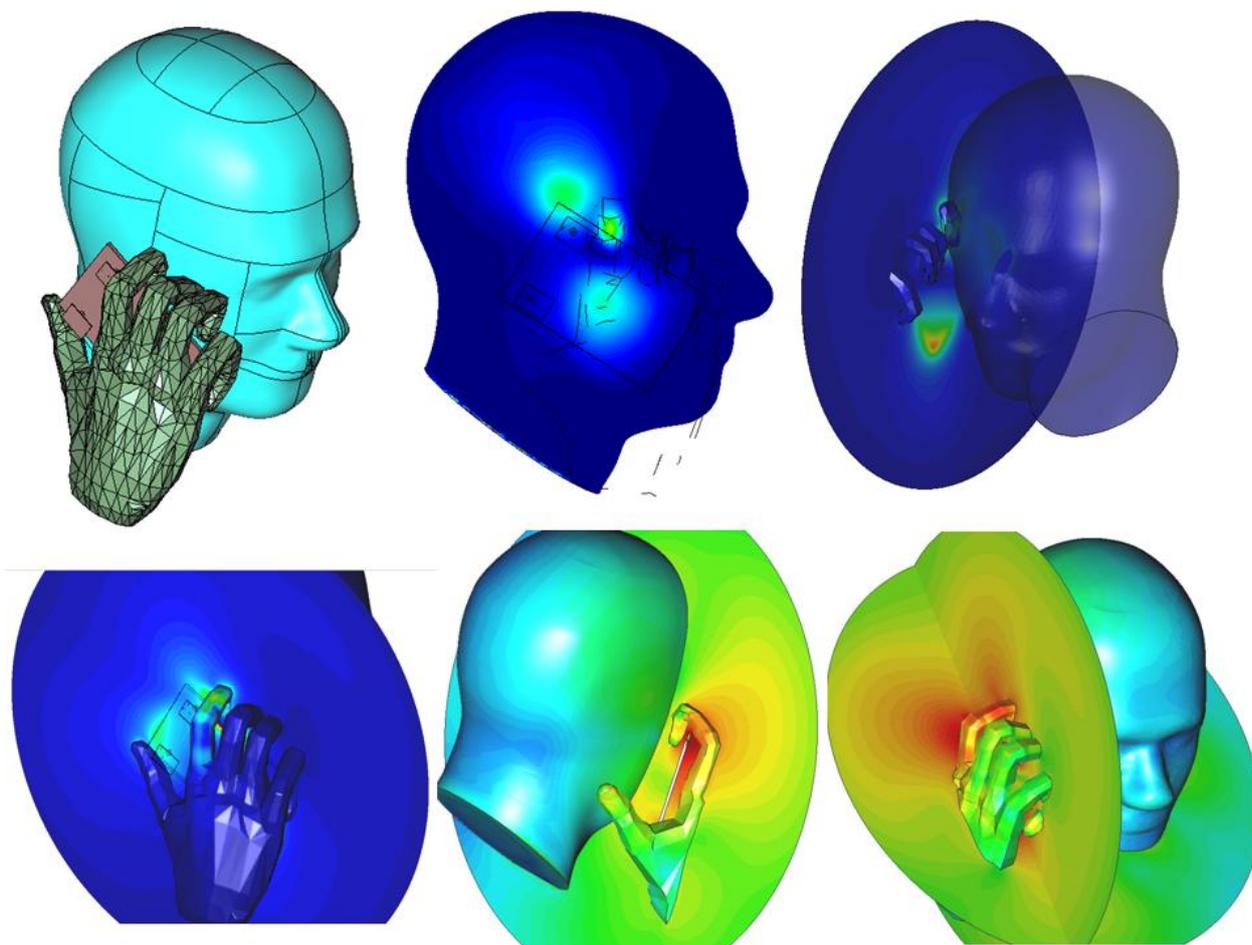
The input data for the simulations are:

$P = 0.10 \text{ W (20 dBm)}$
 $f = 1800 \text{ MHz}$
 $\rho = 1000 \text{ Kg/m}^3$

$\epsilon_r(\text{head}) = 43.5$
 $\sigma(\text{head}) = 1.15 \text{ S/m}$

$\epsilon_r(\text{hand}) = 37.6$
 $\sigma(\text{hand}) = 1.43 \text{ S/m}$

The distance from feeding point to **SAM head** = **0.03 m**, and the result of the simulation with ERMES is **max. SAR (head) = 0.04 W/Kg**.



7. CONCLUSIONS AND FUTURE DEVELOPMENTS

After a careful examination of the simulations described in this report, we can conclude that ERMES gives accurate results and that it can solve efficiently SAR problems. However, there are some scenarios in which the efficiency can be put in jeopardy:

1-) Too many singularities in the domain (metallic or dielectric edges and corners):

The need of meshing with small elements to catch the behaviour of the fields near the singularities increase dramatically the number of unknowns, therefore, the computational cost is increased. Moreover, the user must be very careful selecting the sizes of the mesh when the singularity interacts strongly with the environment.

In conclusion, **we must research more in deep how to improve the performance of ERMES when electric field singularities are present in the domain.**

2-) Source (antenna) and target (dielectric body) are far away from each other:

The finite element method needs to calculate the electric field in the space surrounding source and target. If the distance between source and target is large, the volume needed to run the simulation is large; therefore, the computational cost is high. A possible solution to improve the performance of ERMES in these cases is the implementation of hybrid methods (e.g. FEM-MoM).

In conclusion, **we must research about hybrid methods.**

SMART project has allowed CIMNE to develop a new finite element formulation called **HORUS** (High ORder elements Un-gauged near the Singularity). HORUS is the finite element formulation behind **ERMES** (Electric Regularized Maxwell Equations with Singularities), a C++ code that uses **GiD** (www.gidhome.com) as interface. As a consequence, one of the deliverables of SMART is a user-friendly computational tool ready to be used for SAR calculations.

SMART project has allowed demonstrating the usefulness of ERMES for professional electromagnetic modelling has increased CIMNE know-how and experience in the electromagnetic field and has set up links between CIMNE and the industry and other university departments.

But, although the current ERMES version is suitable for solving SAR problems in near field, further research is required to develop specific formulations and numerical models for electrically large structures e.g. base station antennas with entire body models or complex car configuration with the presence of different passengers. Hybridization of the FEM formulation developed in SMART with MoM and high-frequency methods like PO, GTD or UTD could be investigated and implemented in order to be able to solve such electrically large problems. Also new features could be added and enhancements in the existing ones would improve the computational performance of the SAR tool, for instance:

- Incorporation of far field patterns.
- Improvements in the radiation boundary conditions.
- Improvements in the modelization of the electric field singularities.

This let the door open for new projects which allow CIMNE to develop a better and more useful SAR computational tool.

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